Possible eRHIC-related studies

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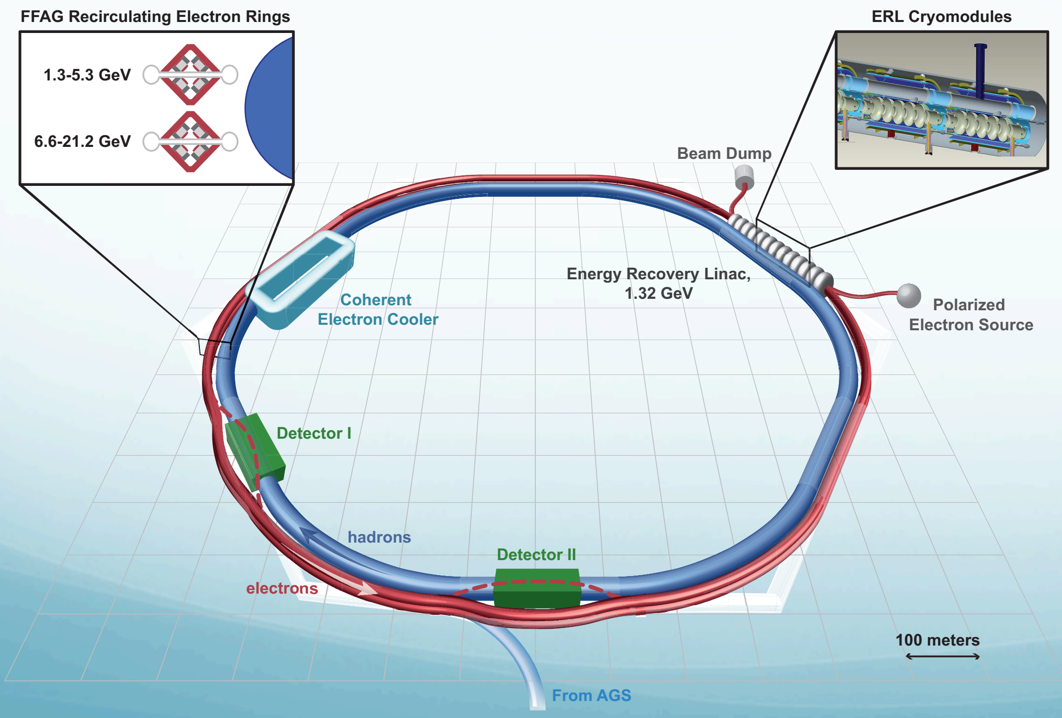
Motivation for beam experiments

- Verify some of approaches and techniques used in the eRHIC design.
- Emulate beam dynamics effects expected in eRHIC.
- Get better quantitative knowledge of hadron machine characteristics used in the design of eRHIC systems.
- Test the feasibility of eRHIC beam parameters.

FFAG eRHIC Design

- Up to 21.2 GeV electron beam accelerated with Energy Recovery Linac (ERL) inside existing RHIC tunnel collides with existing 250 GeV polarized protons and 100 GeV/n HI RHIC beams
- Single collision of each electron bunch allows for large disruption, giving high luminosity and full electron polarization transparency
- Use 2 FFAG magnet strings in RHIC tunnel to transport up to 16 beams
- Considered permanent magnet design for FFAG lattice magnets
- Cool hadron beam 10-fold in all directions using coherent electron cooling (CeC) at reduced intensity of hadron beam
- IR design with $\beta^*= 5$ cm using SC magnet technology and crab-crossing scheme
- Average polarized electron current of up to 50 mA



Baseline design beam parameters

	e	p	$^{2}He^{3}$	$^{79}Au^{197}$
Energy, GeV	15.9	250	167	100
CM energy, GeV		126	103	80
Bunch frequency, MHz	9.4	9.4	9.4	9.4
Bunch intensity (nucleons), 10^{11}	0.07	3.0	3.0	3.0
Bunch charge, nC	1.1	48	32	19.6
Beam current, mA	10	415	275	165
Hadron rms normalized emittance, 10^{-6} m		0.2	0.2	0.2
Electron rms normalized emittance, 10^{-6} m		23	35	58
β*, cm (both planes)	5	5	5	5
Hadron beam-beam parameter		0.004	0.003	0.008
Electron beam disruption		36	16	6
Space charge parameter		0.08	0.08	0.08
rms bunch length, cm	0.4	5	5	5
Polarization, %	80	70	70	none
Peak luminosity, 10^{33} cm^{-2}s^{-1}		4.1	2.8	1.7

Proton beam parameters

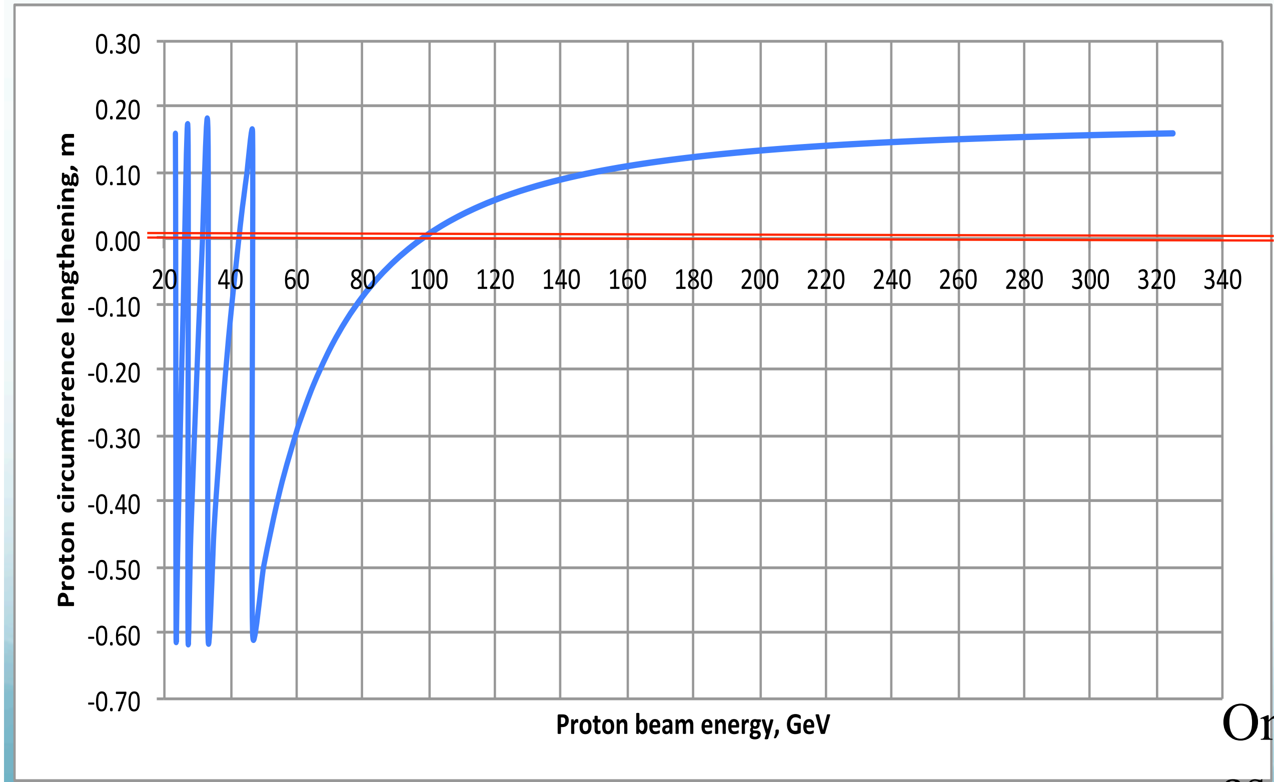
	eRHIC (2014)	Achieved at RHIC
Energy, GeV	100-250	Runs at 31, 100, 250 (255) GeV
Number of bunches	111	111
Bunch intensity, 10^{11}	3	1.8 (at store)
Normalized 95% emittance, 1e-6 m	1.2	~15-20 mm*mrad at the store
beta*, cm	5	65
rms bunch length, cm	5	~50 cm
Store polarization	70%	~62% at 100 GeV, ~58% at 250 GeV

eRHIC-related studies

1 . Circumference lengthening.
2. Interplay of space-charge and beam-beam effects.
3. Study of bunch length limits.
4. Longitudinal impedance and the microwave instability threshold
5. Transverse impedance and the intensity limits, feedback systems
6. Intensity limits: beam instrumentation, BPM cable heating
7. Control of s*.

Proton delay line

In order to match bunch frequencies of electrons and protons we need to vary the proton circumference with proton energy.



Present design assumes circumference variation **up to 16 cm**
If more can be achieved, only better.

One way: cosntruct delay line, as a string of movable magnets
Costly solution.

Delay line by radial closed orbit shifts

T. Roser's idea

Radial orbit shift using bending magnets at fixed energy:

$$\frac{\Delta L}{L} = \frac{1}{\gamma_t^2}\left(\frac{\Delta p}{p} - \frac{\Delta B}{B}\right) \xrightarrow[\frac{\Delta p}{p}=0]{} -\frac{1}{\gamma_t^2}\frac{\Delta B}{B}$$

Change of all bending magnets by same relative amount and RF frequency

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Radial orbit shift with fixed bending field:

$$\frac{\Delta L}{L} \xrightarrow[\frac{\Delta B}{B}=0]{} -\frac{\gamma^2}{\gamma^2 - \gamma_t^2}\frac{\Delta f_{rev}}{f_{rev}} \qquad \Delta L = \pm 8cm \rightarrow \frac{\Delta f_{rev}}{f_{rev}} = \pm 1.2 \cdot 10^{-6} \quad ; \quad \frac{\Delta p}{p} = \pm 0.009$$

Change only RF frequency. Allow for slight variation of the beam energy.

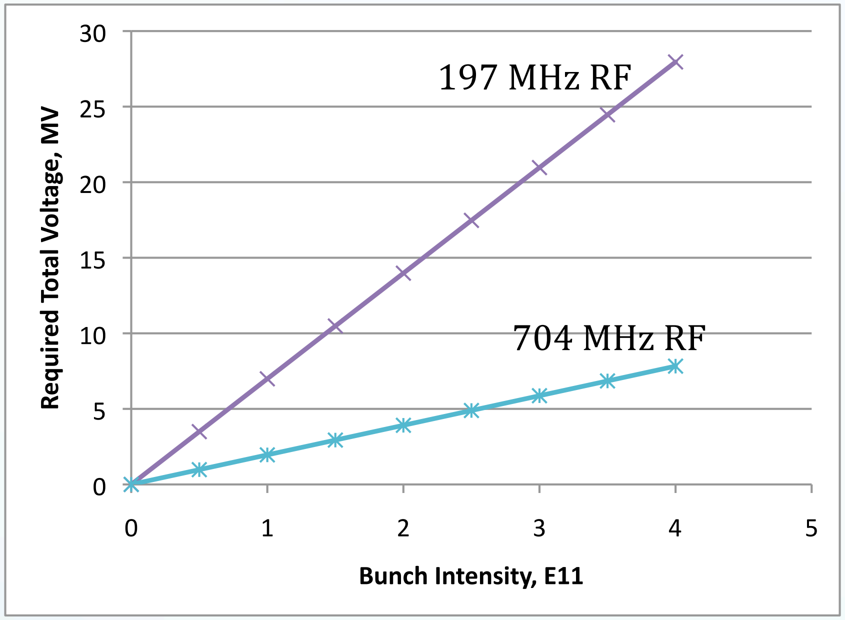
Circumference lengthening studies

- We want to demonstrate radial shifts in arcs at least up to 1.3 cm.

- We will apply corresponding RF frequency (and bending field) adjustments and measure beam lifetime with and without collisions.

Tune/coupling feedback will be used

RHIC Longitudinal Impedance



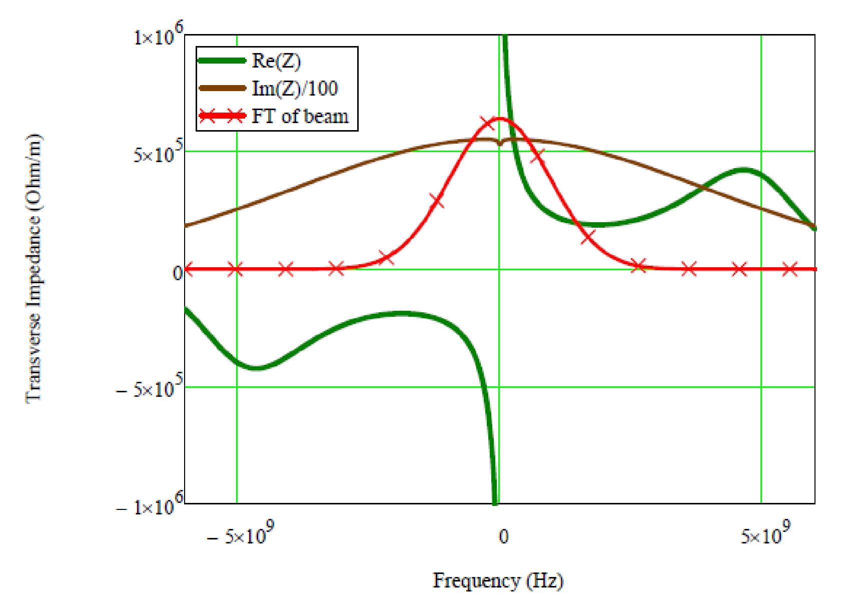
For longitudinally cooled beam in eRHIC the microwave instability is possible.
The longitudinal impedance defines the requirements for the RF system (harmonic and voltage) needed to prevent the instability .

Last run data (from M. Blaskiewicz):
Blue: 2 Ohm
Yellow: 5 Ohm

The plot shows the required RF voltage based on the longitudinal (broadband) impedance 3 Ohm.

This is the measured value of the impedance:
M. Blaskiewicz, J. M. Brennan, P. Cameron, and W. Fischer. "Longitudinal Impedance Measurement in RHIC." *EPAC 2002*
(the synchrotron tune shift versus the bunch intensity)

RHIC transverse impedance



Transverse impedance model is used (G.Wang, M.Blaskiewicz) to evaluate eRHIC transverse instabilities.

Both multi-bunch and single bunch transverse instabilities are observed in eRHIC studies (for 10^{34} cm^{-2} s^{-1} luminosity)

Better knowledge of the RHIC transverse impedance would lead to better definition of the remedies:
octupole strength or feedback system parameters.

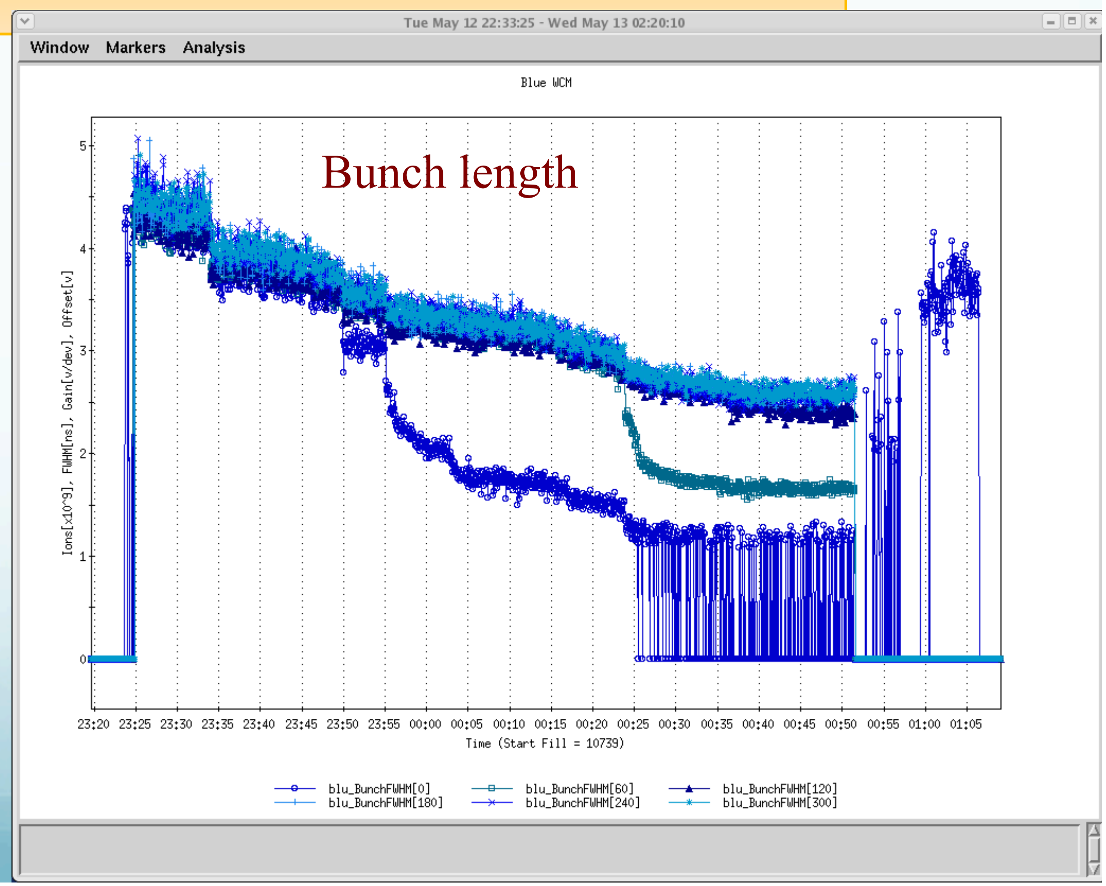
Study of bunch length limits

Goals:

- To identify and observe effects which may put limits on the minimum bunch length in RHIC.
- To distinguish the limitation coming from resistive wall heating and electron cloud (vacuum, pipe heating) and identify the heat load on the beam pipe from both effects.

Approaching transition using gammaT quads. Run-9 APEX studies.

Conclusion: need to automate process and use feedbacks (tune,coupling,orbit)

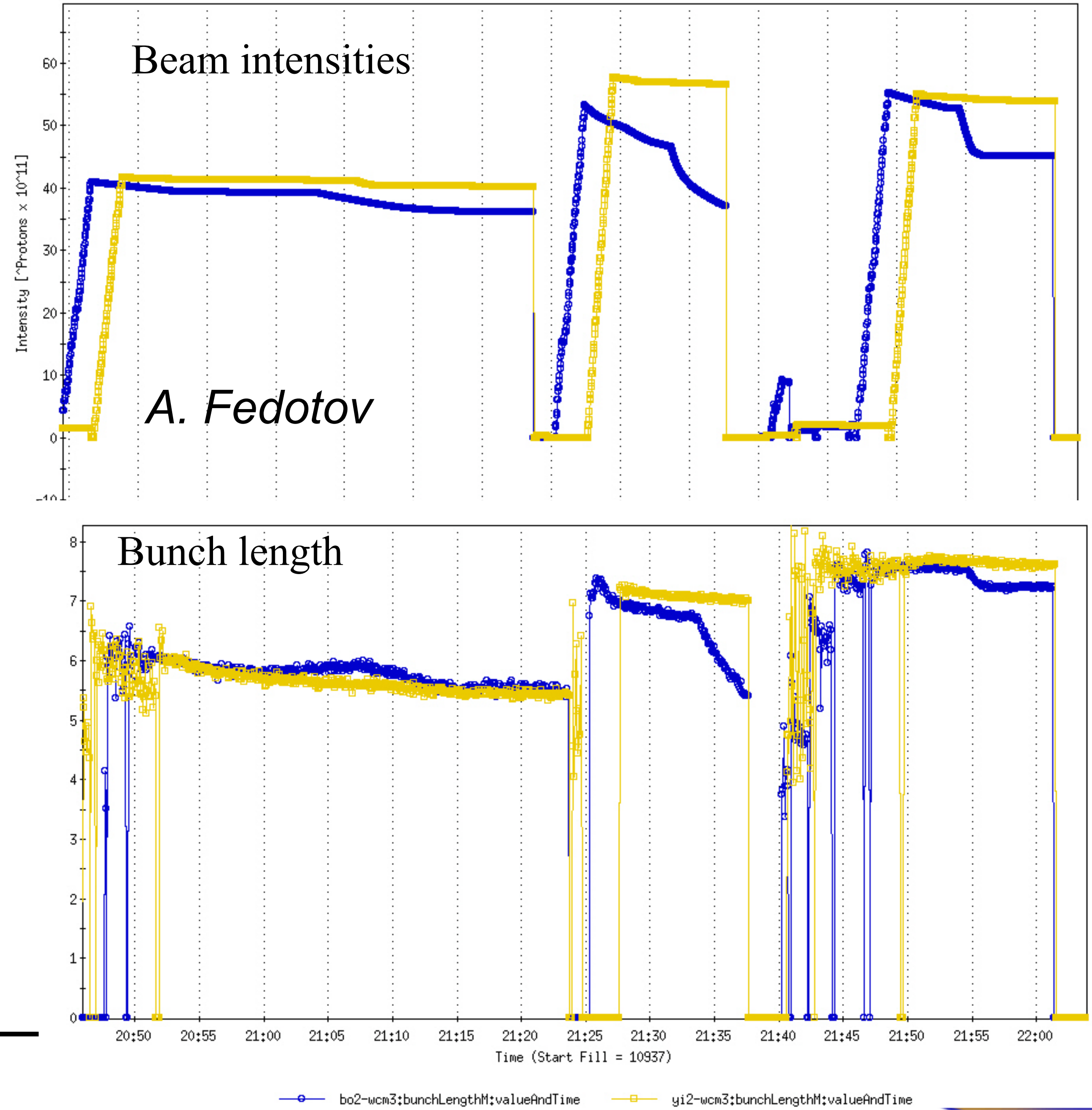


Interplay of space-charge and beam-beam effects

Protons
@γ=25

$\Delta p/p = 1.5 \cdot 10^{-3}$

Losses are seen in the longitudinal plane



In eRHIC:

$\Delta p/p = 3 \cdot 10^{-4}$

Plan for space charge studies with proton beam

Assumed eRHIC limit: ΔQ_{sp} =0.08

Remaining question from previous studies:
-What would be the beam lifetime with the momentum spread more similar to the eRHIC value?

Suggested measurements with protons:
-Compare the beam lifetime obtained at different momentum spread (9 MHz versus 28 MHz RF system) but at the same space charge and beam-beam parameters.

-Do the measurement at (0.69,0.68) working point area; compare the beam lifetimes with exchanged Blue and Yellow working points.

-If studies with for the Integer working point are planned, take the advantage of machine tuning done during that studies and do the measurement at that working point area.

Beam-beam interactions

Y. Hao

Control of beta-function minimum location is important:

Change of s* in eRHIC by 10 cm -> ~30% luminosity loss

Studies to demonstrate the possibility of the s* control on the scale of several cm are needed

Effect of fluctuations of electron beam parameters (offset, intensity, beam size) on the hadron beam.

e-Lens commissioning and studies may help to learn about this effect and verify the eRHIC expectations.
2-3 μm rms electron position error in IP is expected